[BAU Journal - Creative Sustainable Development](https://digitalcommons.bau.edu.lb/csdjournal)

Volume 2 | Issue 1
ISSN: 2664-9446

Article 10

November 2020

USING CONE-BEAM COMPUTED TOMOGRAPHY TO EVALUATE APICAL TRANSPORTATION AND CENTERING ABILITY OF WAVEONE, ONESHAPE AND TORNADO ROTARY SYSTEMS: A CLINICAL STUDY

Alaaeldeen O. Mais
PHD program Resident, Division of Endodontics, Department Of Restorative Sciences, Faculty of Dentistry, Beirut Arab University, alaa_mais@hotmail.com

Amr M. Abdallah
Professor of Endodontics, Division of Endodontics, Department of Restorative Dentistry, Faculty of Dentistry, Alexandria University, dr_amr_abdallah@hotmail.com

Essam Osman
Professor of Dental Biomaterials,Faculty of Dentistry,Beirut Arab University, Beirut, Lebanon, essamosman11@gmail.com

Canal transportation, Canal centering ability, nickel-titanium files, Tornado rotary system, Cone-beam Computed Tomography

USING CONE-BEAM COMPUTED TOMOGRAPHY TO EVALUATE APICAL TRANSPORTATION AND CENTERING ABILITY OF WAVEONE, ONESHAPE AND TORNADO ROTARY SYSTEMS: A CLINICAL STUDY

Abstract

This clinical study was aimed to evaluate apical transportation and centering ability of WaveOne, OneShape files and Tornado rotary system using Cone-beam computed tomography (CBCT). Lower molars with a curving angle of buccal canals extending from 15°-45° in 24 patients were arbitrarily divided into three groups (n=8) rendering to the rotary systems used: Group 1, Tornado system, Group 2, WaveOne rotary system, and Group 3, OneShape rotary system. CBCT was used as a diagnostic method to evaluate centering ratio and canal transportation at 2, 5 and 8 mm from apical foramen. One-way analysis of variance and post hoc Tukey tests were used for statistical analysis at $p \leq 0.05$. No statistically significant difference in the magnitude of transportation and centering ability was found at all tested levels ($P>0.05$). WaveOne and OneShape nickel-titanium files and Tornado stainless-steel file conserved the original canal curvature with no significant variance.

Keywords

Canal transportation, Canal centering ability, nickel-titanium files, Tornado rotary system, Cone-beam Computed Tomography

1. INTRODUCTION

Cleaning and shaping in endodontic treatment are very important steps aimed at removing bacteria and debris that may cause endodontic failure (Machado et al. 2010). The aim of endodontic instrumentation is to form a constantly apically tapering canal to allow active irrigation and filing (Schilder 1974). This may represent a great challenge to endodontists particularly when handling curved canals (Hadhoud 2019). Mistakes such as zipping, ledges, root canal transportation and perforations, are common during curved canal instrumentation. These mistakes might occur due to the propensity for wholly instrumentation methods and instruments to turn away the canal far from its novel axis (Weine et al. 1975). Several procedures together with rotary nickel-titanium Nickel Titanium systems and diverse kinematics have been established to preserve the canal's original shape, allow enhanced canal centralization, and hasten canal preparation (Schafer & Florek 2003).

Nickel-titanium files were found to have superior elasticity and resistance to torsional breakage when related to hand stainless steel files (Walia et al. 1988). Asymmetric reciprocation of a single file system was described by Johnson et al. (Johnson el al. 2008) to decrease instrumentation time and cost, and to enhance its safety. WaveOne (Dentsply Maillefer, Ballaigues, Switzerland), a reciprocating file system that needs a special motor mechanism was prepared of a special Nickel Titanium alloy (M-wire) that is formed by an advanced thermal treatment method (Johnson el al. 2008). The M-wire is characterized by superior elasticity and resistance to cyclic fatigue (Shen et al. 2006). The reciprocating motion consists of two rotating angles, the first one is a large angle (counter-clockwise direction) where the file progresses in the canal engaging dentin into its flutes to cut, while the smaller angle in the clockwise direction decreases the screwing effect and file breakage due to immediate disengagement and careful progression along the canal path (Plotino et al. 2012).

OneShape (Micro Mega, Besancon, France) NiTi files, utilized in constant rotating motion, were developed for curved canals with a special design that includes different cross sections along its length to enhance cutting action about three regions of root canal. Superior apical progression is due to its high cutting efficacy and flexibility that minimizing the instrument fatigue and diminishes the risk fracture (Gernhardt CR 2013).

Several studies have presented the inferior mechanical properties of stainless-steel instrments when compared with NiTi instruments. A new stainless-steel file system was developed special features and suggest having greater qualities as compared to NiTi files (Moreinos et al 2016). The tip of the file is made up of a main central braided chain with a diameter fewer than 0.15 mm. Coiled on uppermost of it is another wire with a width less than 0.20 mm. In the central and higher parts of the file, a third wire fewer than 0.35 mm width is coiled. The apical 0.5mm of the termination of the instrument sharpened at a 45˚angle results in a non-cutting tip. All files have a continuous 4% taper. The files are operated by a special completely automated handpiece at a greatest speed of 6500 rpm. The speed changes automatically, liable on the strength applied to the file while rotating in the canal. The system is made up of of six files, an orifice opener of 18 mm length and five preparation files each of 25 mm length. According to the manufacturer's directions, canals should be instrumented by using two to three files. The variability of files in the system is intended to allow the endodontist to select the most appropriate file combination for the exact canal anatomy (Moreinos et al 2016).

Cone beam computed tomography (CBCT) imaging has been promoted to estimate changes of root canal geometry before and after instrumentation. This nondestructive method is capable of a qualitative and quantitative valuation of the root canal system in three dimensions (Zhao et al. 2013). The aim of this investigation is to compare apical transportation and centering ability in curved root canals instrumented with a single WaveOne reciprocating file, single OneShape rotary file and Tornado rotary stainless-steel system using CBCT. The null hypotheses tested were that there is no difference between the three rotary systems regarding canal centering ability and transportation in severely curved root canals.

2. MATERIALS AND METHODS

Patients enrolled in this randomized clinical trial were selected arbitrarily from patients assigned to the Endodontics department (Beirut Arab University) for initial nonsurgical root canal treatment. Ethical clearance for the study was obtained from the Institutional Review Board.

Twenty-four patients having lower molars with two distinct mesial canals were chosen. The canals should have separate apical foramen with mature apices and no resorption or cracks (Deepak et al. 2015). Mesial canals having curvature within 15°-45° limit (Canal curvature was determined with using Schneider method) (Schneider 1971). Patients less than 16 or more than 65 year-old, or having immune-compromising disease or diabetes or their teeth had been previously accessed or treated were excluded from the study (Gill et al. 2016). Patients fulfilled the inclusion criteria were asked to sign a consent form after explaining the possible discomfort or risks and possible benefits as approved by the Institutional Review Board (IRB) at Beirut Arab University.

All patients were evaluated and assessed by appropriate history taking, and clinical and Pre-operative digital radiographic examination. The history of the patient was gathered and recorded in full details as demographic data, chief complaint, past medical and dental histories. All the teeth were scanned using a CBCT (Kodak 9000C) with 80 kV, 4 mA, 51 × 51 mm field of view and 0.1/voxel (mm) size. The teeth were scanned at 2, 5 and 8mm from the apex of the canal in an axial slice thickness of 0.1mm. The values were recorded in the computer and patients were arbitrarily divided into three equal groups (n=8):

Group 1: Were instrumented using Tornado system (Rotary stainless-steel system)
Group 2: Were instrumented using WaveOne system (Reciprocating system)
Group 3: Were instrumented using OneShape system (Rotary NiTi system).

After proper anesthesia and isolation, access cavities were done with round bur followed by Endo Z bur and apical patency were evaluated with stainless steel K-file #10. The working length (WL) was recognized using apex locator and confirmed using periapical X-ray. Canal preparation was done using a glide path of size 15 K-type file and RC prep. All root canals were irrigated using 2 ml of a 2.5% sodium hypochlorite solution after use of each instrument. All root canals were irrigated using 3.0 mL of 17% EDTA for 1 min followed by 1.3% NaOCl. (Deepak et al 2015).

In group 1 (*Tornado file system*), the system was activated using a specifically designed handpiece at 6500 rpm. Eight samples were instrumented according to the recommendations of the manufacturer. The canals were finalized with apical diameter of 0.25mm with taper of 4%. In group 2 (*WaveOne system*), the system was activated by means of a torque control endodontic hand piece (X smart plus with reciprocation mode) and the canals were instrumented according to manufacturer's directions. The file system has a tip diameter of 0.25 mm and a taper of 0.08 in apical 3 mm. In Group 3 (*OneShape System*), canal instrumentation was done using torque control endodontic hand piece (X smart plus rotational speed 250r.p.m.) according to the manufacturer's recommendation. Finishing the canals was done by instrument having apical diameter of 0.25mm and 6% Taper.

After instrumentation, all teeth were imaged in a similar way similarly as pre-instrumentation images. The images were stored in the computer and cross sectional planes of images at 2, 5, and 8 mm away from the apex of both canals of mesial root were examined before and after instrumentation for centering ability and transportation (Celikten et al. 2015).

Evaluation of canal transportation:

The amount of canal transportation in the mesial-distal direction was determined by measuring the shortest distance from the periphery of un-instrumented canal to the border of the root (mesial and distal) and then comparing this with the same measurements achieved from the instrumented images. Two evaluators measured all the values and a mean number was taken. According to (Gambill et al. 1996), the following formula was used for measuring transportation:

$$\textit{Canal transportation } CT = (M1 - M2) - (D1 - D2)$$

(Where M1 refers to the shortest distance from the mesial edge of the root to the mesial edge of the un-instrumented canal, M2 refers to the shortest distance from the mesial edge of the root to the mesial edge of the instrumented canal, D1 refers to the shortest distance from the distal edge of the root to the distal edge of the un-instrumented canal and D2 refers to the shortest distance from the distal edge of the root to the distal edge of the instrumented canal).

According to this formula, a result of 0 denoted lack of transportation, a negative value denoted transportation towards the distal direction, and a positive value denoted transportation towards the mesial direction.

Evaluation of centering ability:

The mean centering ratio indicates the ability of the instrument to stay centered in the canal. It was calculated for each section by using the following ratio:

Centralization ability ratio = (M1- M2) / (D1- D2) or (D1-D2) / (M1-M2)

The formula was selected in such a manner that the lowest of the results acquired through the difference should be the numerator. A result equal to 1.0 signified perfect centralization. When the value was closer to zero, it denoted that the instrument had lower capacity to maintain itself in the central axis of the canal. Then, all teeth in the three groups were obturated by Gutta percha and sealer (Resin sealer) using the same obturation technique (Lateral condensation technique).

Statistical Analysis

The values of pre- and post-instrumentation were recorded in excel spreadsheet and the statistical analysis were performed using Statistical Package for the Social Sciences (SPSS) software (SPSS 22, SPSS Inc, Chicago, IL). The means and standard deviations were calculated for each group. One-way test of significance was used to determine the difference among groups and Tukey significant difference post hoc test was performed for significant differences between groups. Since the data did not follow the normal distribution, Kruskal-Wallis test was used for testing significance difference and p-value ≤05 was regarded as significant.

3. RESULTS

Twenty-four patients were enrolled in this study with a mean age of 35.7 ± 10.1 years old. No significant differences in apical transportation and centering ability were found between the WaveOne, OneShape and Tornado systems in both mesial canals ($p \geq 0.05$). Table 1 summarizes the results of canal transportation in the MB canal. Table 2 summarizes the Comparison of canal transportation at 2, 5, 8 mm from apex between files systems in ML canal.

No statistically significant difference between the centering ability of the three systems at each tested root level was found ($p > 0.05$). Table 3 summarizes the results of centering ability in the MB canal. Table 4 summarizes the results of canal centering ratio between file systems in ML canals. No statistically significant difference of centering ability at each root level was found between the three systems (p-values > 0.05).

Proper centering ability and no transportation are observed in figures 1, 2, 3 and 4, using the three different files.

Figures 1, 2, and 3 showing proper centering ability and no transportation at 8mm from the apex of the three rotary systems using CBCT.

Table 1: Canal transportation in the MB canal. Mean, standard deviation (SD) and results of Kruskal-Wallis test for comparison between canal transportation values (mm) after using the three systems in MB canal.

Reference: Done by the Author

Root Level	OneShape		WaveOne		Tornado		Kruskal-Wallis test
	Mean	SD	Mean	SD	Mean	SD	P-value
2 mm	0.0125	0.112599	0.0125	0.099103	-0.025	0.10351	0.662
5 mm	0.025	0.10351	0	0.130931	0.0375	0.051755	0.474
8 mm	0.0375	0.091613	0	0.075593	-0.025	0.046291	0.299
Total	0.075	0.307722	0.0125	0.305627	0.0875	0.201556	0.123

Table 2: Canal transportation in the ML canal. Mean, standard deviation (SD) and results of Kruskal-Wallis test for comparison between canal transportation values (mm) after using the three systems in ML canal.

Reference: Done by the Author

Root Level	OneShape		WaveOne		Tornado		Kruskal-Wallis test
	Mean	SD	Mean	SD	Mean	SD	P-value
2 mm	0	0.092582	0.025	0.10351	0.025	0.10351	0.809
5 mm	-0.0125	0.064087	-0.025	0.10351	-0.0125	0.083452	0.980
8 mm	-0.0375	0.074402	-0.025	0.138873	-0.025	0.10351	0.926
Total	-0.05	0.231071	-0.025	0.345893	-0.0125	0.290472	0.874

Table 3: Centering ability in the MB canal. Mean, standard deviation (SD) and results of Kruskal-Wallis test for comparison between centering ability values (mm) after using the three systems.

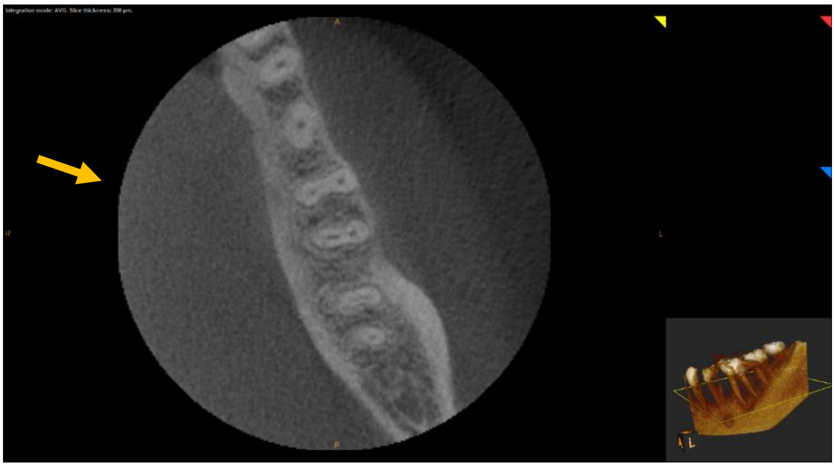
Reference: Done by the Author

Root Level	OneShape		WaveOne		Tornado		Kruskal-Wallis test
	Mean	SD	Mean	P-value	Mean	SD	p-value
2 mm	0.645	0.225	0.5825	0.177	0.738	0.233	0.298
5 mm	0.68625	0.274	0.6225	0.264	0.832	0.236	0.272
8 mm	0.74875	0.282	0.7075	0.364	0.895	0.199	0.425
Total	2.08	0.783	1.9125	0.806	2.466	0.669	0.342

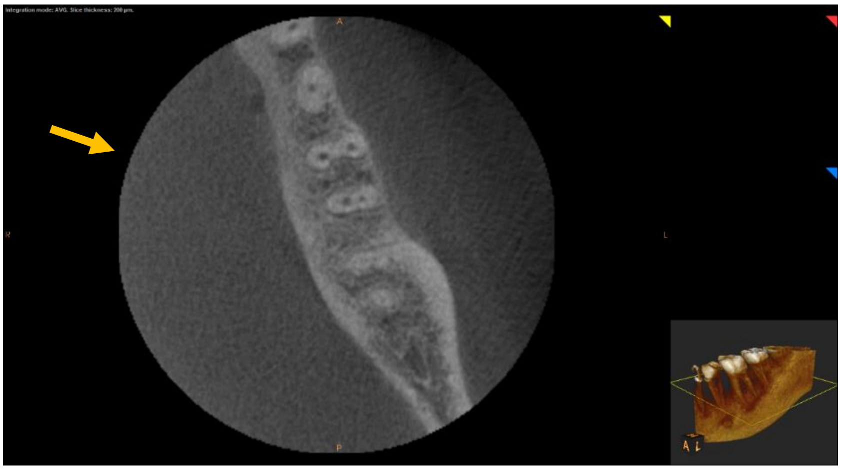
Table 4: Centering ability in the ML canal. Mean, standard deviation (SD) and results of Kruskal-Wallis test for comparison between centering ability values (mm) after using the three systems.

Reference: Done by the Author

Root Level	OneShape		WaveOne		Tornado		Kruskal-Wallis test
	Mean	SD	Mean	P-value	Mean	SD	p-value
2 mm	0.791	0.292	0.68625	0.274	0.68625	0.274	0.732
5 mm	0.791	0.292	0.70625	0.264	0.73875	0.233	0.832
8 mm	0.727	0.235	0.59375	0.265	0.54	0.074	0.188
Total	2.31	0.820	1.98625	0.804	1.965	0.582	0.179

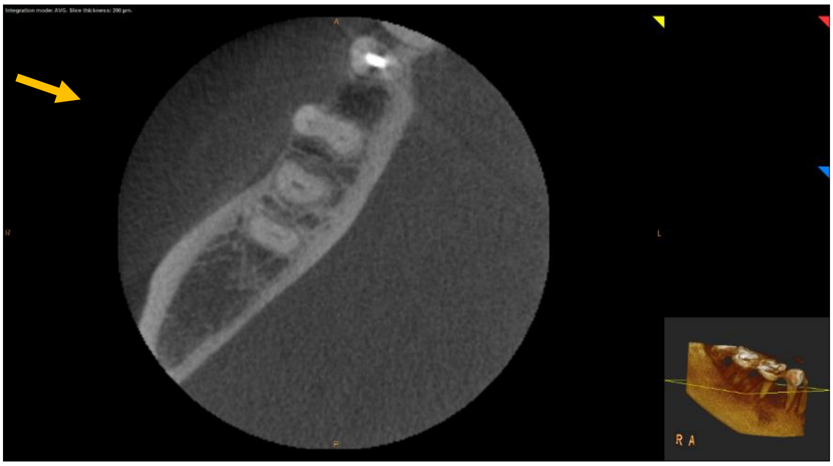


Before (A)

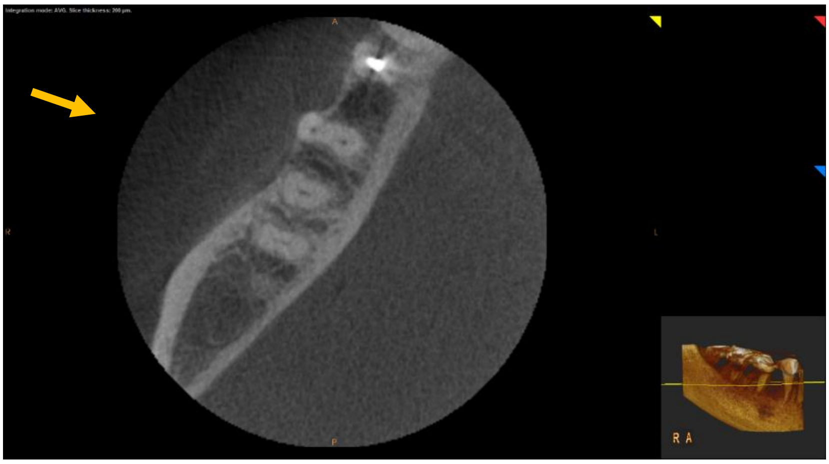


After (B)

Fig.1: Representative CBCT scans before (A) and after (B) instrumentation Group 1 Tornado system at 8 mm from the apical foramen in MB canal.
Reference: Photographed by the author September 20

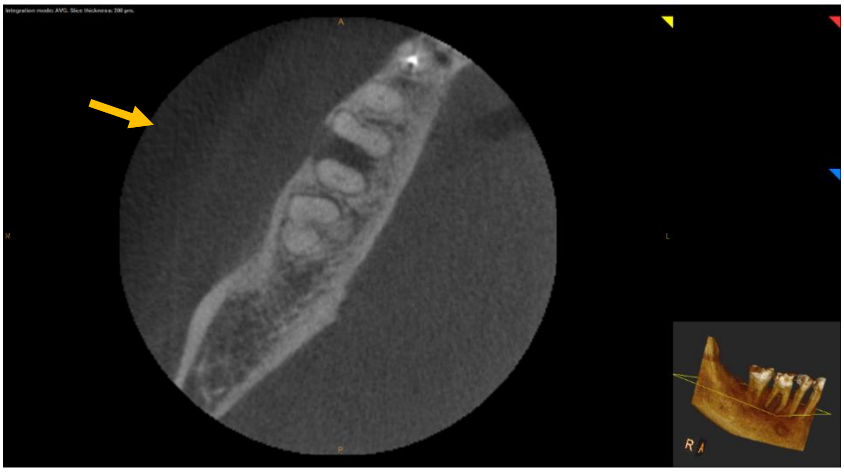


Before (A)

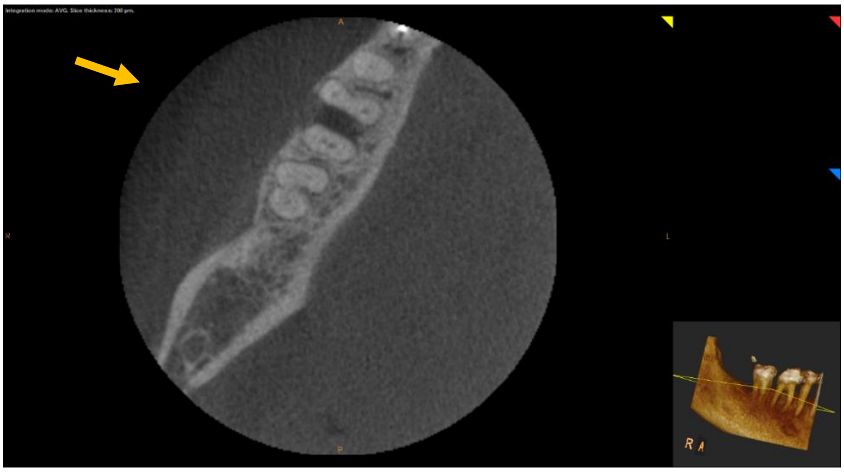


After (B)

Fig.2: Representative CBCT scans before (A) and after (B) instrumentation Group 2 WaveOne system at 8 mm from the apical foramen in MB canal.
Reference: Photographed by the author September 20



Before (A)



After (B)

Fig.3: Representative CBCT scans before (A) and after (B) instrumentation Group 3 OneShape system at 8 mm from the apical foramen in MB canal.
Reference: Photographed by the author September 20

4. DISCUSSION

Since success of all succeeding steps following canal preparation is determined by its proper preparation, proper instrumentation and effective irrigation are required to attain the root canal treatments objectives (Yared 2010). Since the early 1960's, several NiTi rotary systems were introduced to the endodontic instruments. Nowadays, single file (NiTi) rotary systems are clinically highly accepted since the decrease time needed for biomechanical preparation and related instrumentation failures. (Burklein et al 2012). These systems can be utilized in two ways: continuous rotation or reciprocal motion. The working part of OneShape instruments have variable cross-sectional designs and different pitch length. This design aids in eradicating binding and threading of this file when rotating continuously (Dhingra et al. 2014). The reciprocating motion acts to decrease the taper lock problem by frequently reversing the rotation direction and minimizing the instrument flexural and torsional and stresses (Burklein et al. 2012).

During canal preparation, apical canal transportation can occur due to the tendency of instruments to reestablish their basic linear shape by removing the wall structure of the canals outside curve (Glossary of Endodontics 2012). Wu et al. (2000) mentioned that sealing of the obscuration is negatively affected when the apical transportation is more than 300 μm. In the current study, centering ability and transportation of WaveOne, OneShape and Tornado systems were evaluated in mandibular molars. Mandibular molars with acute curved mesial roots were chosen since they have a high level of instrumentation difficulty due to their slender and curved nature in two planes (Berutti et al. 1992) and it is verified that all preparation techniques and instruments tend to change the pathway of the curved root canal (Khandelwal & Palanivelu 2020). Schneider method, a simple and commonly accepted method, was used in our study for assessing root canal curvature (Schneider 1971).

To measure canal transportation and centering ability, CBCT examination of the root canals was used before and after instrumentation (Nur et al. 2014). This type of analysis was chosen since it proved to be one of the most precise methods for centering ability of various rotary systems (Elsherief et al. 2013). Moreover, it is proven to be a nondestructive method (Pawar 2020). According to (Gambill et al. 1996) formula, the amount of centering ability and canal transportation at different levels (2 mm, 5 mm and 8 mm) from the apex was evaluated. Taking into consideration that highly curved canals were prepared in this study, yet its' clinical relevance remains controversial since the maximum variance in canal straightening was not more than 0.4mm. Therefore, it can be deduced that the all three studied instruments preserved well the original curvature of the canal.

In agreement with previous studies, in this study no significant differences were obtained with regards to the root canal parameters evaluated (Bürklein et al. 2012, Bürklein et al. 2013 and Capar et al. 2014). In a previous study done on extracted teeth, Reciproc, WaveOne, and OneShape were found to preserve the original curving of highly curved canals (Bürklein et al. 2012). Capar et al. (2014) used CBCT imaging for evaluation of transportation and reported that Reciproc, WaveOne, and OneShape preserved equally the curvature and created similar canal transportation of the root canal throughout the preparation of lower molars' mesial canals. However, in our study we used Tornado file system, this special rotary stainless steel files which have a special manufacturing design making it a flexible file, despite this manufacturing difference, no statistically difference was found in terms of centering ability and transportation.

This study was found to have one main limitation, which is its small sample size. Therefore, it is recommended to use a bigger sample size in future investigations. Finally, since the three rotary systems in our study were found to have no significant differences with respect to centering ability and transportation; therefore, the null hypothesis is accepted.

5. Conclusion

Within the limitations of our study, it was found that WaveOne, OneShape and Tornado files are equally suitable for root canal instrumentation as they preserved the original canal anatomy with no significant differences regarding canal transportation or centralization. As regards to clinical relevance, Tornado system is one of the safe instruments to be used in preparing curved root canals.

Acknowledgements

The authors declare that there are no conflicts of interest in this study.

REFERENCES

- *American Association of Endodontists Glossary of Endodontic Terms*. 8th ed. Chicago: AAE; 2012
- Berutti, E., & Fedon, G. (1992). Thickness of cementum/dentin in mesial roots of mandibular first molars. *Journal of Endodontics*, *18*(11), 545-548.
- Bürklein, S., Benten, S., & Schäfer, E. (2013). Shaping ability of different single-file systems in severely curved root canals of extracted teeth. *International Endodontic Journal*, *46*(6), 590-597.
- Bürklein, S., Hinschitza, K., Dammaschke, T., & Schäfer, E. (2012). Shaping ability and cleaning effectiveness of two single-file systems in severely curved root canals of extracted teeth: Reciproc and WaveOne versus Mtwo and ProTaper. *International Endodontic Journal*, *45*(5), 449-461.
- Capar, I. D., Ertas, H., Ok, E., Arslan, H., & Ertas, E. T. (2014). Comparative study of different novel nickel-titanium rotary systems for root canal preparation in severely curved root canals. *Journal of Endodontics*, *40*(6), 852-856.
- Celikten, B., Uzuntas, C. F., Kursun, S., Orhan, A. I., Tufenkci, P., Orhan, K., & Demiralp, K. Ö. (2015). Comparative evaluation of shaping ability of two nickel-titanium rotary systems using cone beam computed tomography. *BMC Oral Health*, *15*(1), 32.
- De Lima Machado, M. E., Sapia, L. A. B., Cai, S., Martins, G. H. R., & Nabeshima, C. K. (2010). Comparison of two rotary systems in root canal preparation regarding disinfection. *Journal of Endodontics*, *36*(7), 1238-1240.

- Deepak, J., Ashish, M., Patil, N., Kadam, N., Yadav, V., & Jagdale, H. (2015). Shaping Ability of 5 (th) Generation Ni-Ti Rotary Systems for Root Canal Preparation in Curved Root Canals using CBCT: An In Vitro Study. *Journal of International Oral Health: JIOH*, *7*(Suppl 1), 57-61.
- Dhingra, A., Kochar, R., Banerjee, S., & Srivastava, P. (2014). Comparative evaluation of the canal curvature modifications after instrumentation with One Shape rotary and Wave One reciprocating files. *Journal of Conservative Dentistry: JCD*, *17*(2), 138.
- Elsherief, S. M., Zayet, M. K., & Hamouda, I. M. (2013). Cone-beam computed tomography analysis of curved root canals after mechanical preparation with three nickel-titanium rotary instruments. *Journal of Biomedical Research*, *27*(4), 326.
- Gambill, J. M., Alder, M., & Carlos, E. (1996). Comparison of nickel-titanium and stainless steel hand-file instrumentation using computed tomography. *Journal of Endodontics*, *22*(7), 369-375.
- Gernhardt, C. R. (2013). One Shape-a single file NiTi system for root canal instrumentation used in continuous rotation. *Endodontic Practice Today, 7*(3).
- Gill, G. S., Bhuyan, A. C., Kalita, C., Das, L., Kataki, R., & Bhuyan, D. (2016). Single Versus Multi-visit Endodontic Treatment of Teeth with Apical Periodontitis: An In vivo Study with 1-year Evaluation. *Annals of Medical And Health Sciences Research*, *6*(1), 19-26.
- Hadhoud, F. M. (2019). Cone beam computed tomography assessment of canal transportation, centering ability, and radius change of two single file systems in curved root canals. *Egyptian Dental Journal*, *65*(3-July (Fixed Prosthodontics, Dental Materials, Conservative Dentistry & Endodontics)), 2739-2747.
- Johnson, E., Lloyd, A., Kuttler, S., & Namerow, K. (2008). Comparison between a novel nickel-titanium alloy and 508 nitinol on the cyclic fatigue life of ProFile 25/. 04 rotary instruments. *Journal of Endodontics*, *34*(11), 1406-1409.
- Khandelwal, A., Palanivelu, Ajitha. (2020). Comparative evaluation of canal transportation and centering ability of WaveOne Gold and EndoSequence Reciprocating File systems using cone-beam computed tomography. *Drug Intervention Today*, 13(2), 1-5.
- Moreinos, D., Dakar, A., Stone, N. J., & Moshonov, J. (2016). Evaluation of time to fracture and vertical forces applied by a novel Gentlefile system for root canal preparation in simulated root canals. *Journal of Endodontics*, *42*(3), 505-508.
- Nur, B. G., Ok, E., Altunsoy, M., Aglarci, O. S., Colak, M., & Gungor, E. (2014). Evaluation of the root and canal morphology of mandibular permanent molars in a southeastern Turkish population using cone-beam computed tomography. *European Journal of Dentistry*, *8*(2), 154.
- Plotino, G., Grande, N. M., Testarelli, L., & Gambarini, G. (2012). Cyclic fatigue of Reciproc and WaveOne reciprocating instruments. *International Endodontic Journal*, *45*(7), 614-618.
- Schafer, E., Florek, H. (2003). Efficiency of rotary nickel-titanium K3 instruments compared with stainless steel hand KFlexofile. Part 1. Shaping ability in simulated curved canals. *International Endodontic Journal*, 36:199–207.
- Schilder, H. (1974). Cleaning and shaping the root canal. *Dent Clin North Am, 18*, 269-296.
- Schneider, S. W. (1971). A comparison of canal preparations in straight and curved root canals. *Oral Surgery, Oral Medicine, Oral Pathology*, *32*(2), 271-275.
- Shen, Y., Cheung, G. S. P., Bian, Z., & Peng, B. (2006). Comparison of defects in ProFile and ProTaper systems after clinical use. *Journal of Endodontics*, *32*(1), 61-65.
- Walia, H., Brantley, W. A., & Gerstein, H. (1988). An initial investigation of the bending and torsional properties of Nitinol root canal files. *Journal of Endodontics*, *14*(7), 346-351.
- Weine, F. S., Kelly, R. F., & Lio, P. J. (1975). The effect of preparation procedures on original canal shape and on apical foramen shape. *Journal of Endodontics, 1*(8), 255-262.
- Wu, M. K., Fan, B., & Wesselink, P. R. (2000). Leakage along apical root fillings in curved root canals. Part I: effects of apical transportation on seal of root fillings. *Journal of Endodontics*, *26*(4), 210-216.
- Yared, G. (2013). Canal preparation with only one reciprocating instrument without prior hand filing: a new concept. 2011.
- Zhao, D., Shen, Y., Peng, B., & Haapasalo, M. (2013). Micro–computed tomography evaluation of the preparation of mesiobuccal root canals in maxillary first molars with Hyflex CM, Twisted Files, and K3 instruments. *Journal of Endodontics*, *39*(3), 385-388.